

Hazardous Solid Waste from Domestic Wastewater Treatment Plants

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The treatment of liquid wastes in municipal sewage treatment plants creates significant quantities of solid residue for disposal. The potential hazard from these wastes requires that their characteristics be determined accurately to develop environmentally sound management criteria. It is readily recognized that the sludge characteristics vary with the type and degree of industrial activity within a wastewater collection system and that these characteristics play a significant role in determining whether the material has potential for beneficial reuse or if it must be directed to final disposal.

This paper offers an overview of past and present practices of sewage sludge disposal, an indication of quantities produced, and experience with beneficial reuse. An estimated range of costs involved, expected environmental effects and potential for continued use is offered for each disposal or reuse system discussed.

Introduction

The collection and treatment of liquid wastes in municipal sewerage produces significant quantities of solid and semisolid residues. While the disposal of these residual sludges has created problems in the past, the recognition of these residues as potentially hazardous has increased the need to determine their true characteristics and develop environmentally acceptable disposal criteria.

Historically, the sludge was returned to the soil as an inexpensive soil additive by farmers located close enough to the treatment plant to justify the haul cost. There was little or no control over this practice and any detrimental effects were either unknown, unreported or impossible to trace to the point of origin.

As expanding population centers forced the farmer to more remote locations and the increased crop yields available from chemical fertilizer made the use of sewage sludge uneconomical, the direct land application of the sewage sludge was essentially abandoned. The disposal of sewage sludge once again became a problem for the treatment plant operator. As with other waste materials, the least costly disposal methods were used without regard to environmental effects. Open dumping, ocean disposal, incineration without air pollution control and other similar practices have been used

up to the present time.

The increase in environmental awareness in recent years and the Resource Conservation and Recovery Act of 1976 require that municipal sewage sludge disposal and/or utilization practices be reevaluated. This paper offers an overview of present practices, their apparent potential for continued use, and a range of costs expected for each.

Sludge Characteristics

Municipal sewage sludge is produced in several forms, depending on the type of treatment used (1). Its characteristics vary significantly and reflect the geographic area and the commercial-industrial activity within the collecting area feeding the wastewater treatment plant. Large metropolitan areas with heavy industrial activity in chemical manufacturing and metal processing will produce a sludge significantly different from areas where little or no industrial activity is present (2). Seasonal variations also occur in some systems where food processing or other similar activities impact the system. Some basic sludge characteristics and their ranges can be seen in Table 1.

While the characteristics vary widely for raw primary sludges, they also vary with the degree of treatment and the treatment process used. Consequently, there is no typical wastewater treatment plant sludge, and the residue from each system must be tested to determine the appropriate final disposal or utilization system.

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Table 1. Partial chemical composition of raw primary sludge.^a

	Range
Total dry solids, %	2.0-7.0
Volatile solids, % of total	60-80
Nitrogen (N), % of total	1.5-4.0
Phosphorus (as P ₂ O ₅), % of total	0.8-2.8
pH	5.0-8.0
Alkalinity mg/l. (as CaCO ₃)	500-1500
Thermal content, BTU/lb (MJ/kg)	6800-10,000 (16-23)

^a Data of Metcalf and Eddy (3).

Sludge Quantities

Sludge quantities also vary with the degree of treatment and the treatment process used. A rule of thumb of 0.25 lb (0.113 kg) per capita per day of suspended solids in sewage entering the treatment plant is normally used for design. The quantity of dry solids removed during treatment ranges from approximately 0.125 lb (0.057 kg) per capita per day of raw sludge from a primary sedimentation plant to as much as 0.35 lb (0.159 kg) per capita per day for advanced wastewater treatment with chemical precipitation. Again, the specific system must be known in order to determine the actual quantity of plant residue which must be considered for disposal or beneficial reuse.

The above quantities are listed on a dry solids basis which is standard practice for wastewater treatment engineering. However, as soon as the material is considered as a solid waste, the total quantity of material to be considered is a combination of the dry solids and water. The water quantity varies from as much as 94 to 96% for thickened, nondewatered sludge to as low as 75 to 78% from some types of dewatering systems.

With the increased level of solids removal of 95 to 96% considered necessary by the regulatory agencies, it is certain that the quantities of wastewater plant sludge will continue to increase. With present solids removal technology, it is reasonable to expect that some form of chemical precipitation will ultimately be required at most large wastewater treatment plants, and higher per capita quantities must be expected. Frequently, the chemical sludges are more difficult to dewater which also affects the total quantity of material to be considered for final disposition.

It is estimated that approximately 162 million people are presently served by municipal sewerage with an estimated sludge quantity of 5 to 6 million dry tons (4.5-5.4 Tg) per year. If secondary treatment were provided on all existing facilities, this quantity would be approximately 10 million dry ton (9 Tg).

Disposal Methods

General Considerations

Some wastewater plant sludges are unsuitable for beneficial reuse within present technology and must be considered suitable only for disposal. As the high cost for environmentally controlled disposal of hazardous wastes is realized, it is expected that more diligent attempts will be made to segregate from the sewage flow the elements which contaminate the total residue and force its disposal. However, it is readily recognized that some form of final disposal will be required for the foreseeable future.

Present disposal practices, without beneficial reuse, can be narrowed to landfilling, incineration and ocean dumping. Ocean dumping is not environmentally acceptable under any set of realistic criteria and no further consideration will be given to this practice except to stress the need for its early termination.

Sanitary Landfilling

Dewatered wastewater treatment plant sludges are frequently incorporated into general solid waste sanitary landfills (4). Basic sanitary landfill design and operating procedures allow this incorporation at an approximate ratio of 20% sludge to 80% general solid waste without adverse effect on the operating procedures. With a wastewater treatment plant residue that is designated as a hazardous waste, this practice can only continue if the sanitary landfill becomes designated a hazardous waste facility.

It must be recognized, however, that some types of highly contaminated sludges with high moisture contents may not be acceptable for direct mixing, even in a designated hazardous waste sanitary landfill. Under present technology, these sludges require segregation and/or encapsulation. Particular care is required during design of the encapsulation to assure that the hazardous material will be either contained forever or eventually corrected by the encapsulation material. Where possible, natural clays such as bentonite or other similar materials having the necessary cation exchange capability can be used in appropriate quantities to allow natural correction. Care must be taken to minimize the penetration of rainwater into the encapsulated cell where it adds to the potential for leachate movement from the area.

An alternative to the above procedure is to provide natural encapsulation and a positive under-drain collection system to remove leachate in a controlled manner. Leachate from this system must

be treated after collection. Again, care must be taken to minimize the penetration of rainwater to reduce the leachate quantity.

Artificial barriers of relatively thin poly(vinyl chloride) membrane have been offered as bottom liners for hazardous waste fills, however the limited experience and life expectancy of these materials makes their use hazardous at this time. The need exists for a suitable artificial barrier for use in areas where natural materials are difficult to acquire, and it is hoped that adequate research will be performed to develop this necessary material.

Regardless of the type of landfill disposal used, the site must be provided with adequate surface water monitoring points and subsurface water monitoring wells to determine whether contaminants are moving from the disposal site and into the surrounding area. A contingency plan for correction must be developed during the design phase in order to avoid the degradation of the surrounding area if an upset occurs. Obviously, the monitoring effort must be continued for many years after the land disposal site has been completely filled.

The cost for sanitary landfilling is less than for any other acceptable disposal method, provided the landfill is located reasonably close to the point of waste generation. Costs of from 3 to 8 dollars per ton (0.33–0.88¢/kg) are considered reasonable for properly operated sanitary landfills with the specific cost being dependent on the size of the operation and the subsequent economy of large scale. With the advent of the hazardous waste disposal requirements, it is expected that these costs will approach 7 to 15 dollars per ton (0.77–1.70¢/kg), again depending on the degree of site preparation and size of the operation. The above costs are on an as-received basis and must be corrected to a dry solids basis for comparison to normal wastewater engineering concepts.

Although sanitary landfill opponents stress the potential for environmental degradation, the history of properly sited, designed, operated and completed facilities does not bear out this contention. While care is required in site evaluation and design for designated hazardous waste land disposal sites, the potential for natural correction makes land disposal one of the safer methods for the disposal of hazardous wastewater plant sludges.

Incineration

In the past, incineration of sewage sludge has been used when sanitary landfills were either too remote from the treatment plant site or considered incapable of properly accepting the sludge. Multiple hearth furnances, variously designed fluidized beds,

flash drying and burning in solid waste incinerators and other variations of the basic combustion process have been used. In the older plants, air pollution control was either nonexistent or was minimal, at best.

There is no question that sludges designated as too hazardous for beneficial reuse will continue to require volume reduction by incineration in areas where designated hazardous waste sanitary landfills are too remote to be economically used. The ash residue from the hazardous sludge combustion process will require disposal in a designated hazardous waste landfill or by encapsulation at the land disposal site, because of the concentration of chemical salts, heavy metals and other similar items in the ash. Conversely, modern combustion process temperatures destroy most pathogens and other heat sensitive organisms which are prevalent in sewage sludge.

In addition to the presently used combustion processes for the volume reduction of sewage sludge, some new concepts, such as pyrolysis and early experimental systems for drying and burning are expected to be available in the future. However, they all have a residue which must be directed to final disposal.

The air pollution control considerations for the combustion of wastewater plant sludge will continue to be a critical item in the selection of the incineration process for sludges considered too hazardous for beneficial reuse. Carcinogenic components and heavy metals are particularly critical in these systems. It is yet to be established that the quantity of carcinogens in the sludge is great enough to warrant concern. Heavy metals are evidenced in the exhaust gas from the combustion process and require special care for their removal.

Electrostatic precipitators efficiently remove dry dust particles from combustion system exhaust gas, with their efficiency being primarily dependent on the electrical resistivity of the particles and the number of electrical fields utilized. However, the potential for an upset in the combustion process when burning sludge alone, offers the possibility of a carbon monoxide rich mixture entering the precipitator. The explosion potential when this occurs indicates that the use of electrostatic precipitators on sludge-only furnaces may be unduly hazardous. Even if this is not the case, additional gas scrubbing will be required to remove gaseous products from the exhaust gas stream.

High energy scrubbing systems offer the greatest potential for acceptable gas cleaning following sludge incineration. Scrubbers with pressure drops in the range of 40 in. (9.9 kPa) are considered adequate to meet the present most stringent air

emission standards. As an additional precaution, the cleaned gases must be discharged to the atmosphere through an elevated stack to gain dispersion of the small remaining quantity of contaminants.

The cost for incineration of sludge is dependent on the size of the facility, the heat content of the sludge and the degree of air pollution control required. Obviously, economies are available at larger facilities which are not available in small plants.

Where incineration of sludge is considered as the only viable alternative, there is no reason to incorporate the digestion process. The digestion process reduces the heat content of the sludge and requires the use of significant quantities of auxiliary fuel to accomplish the necessary burning. Even raw sludge will require some quantity of auxiliary fuel to initiate and sustain uniform combustion. Consequently, any incineration method which allows the combined burning of sludge and solid waste must be considered favorably, because it eliminates the auxiliary fuel requirement and reduces the total disposal cost.

With the present concern for energy recovery, it is necessary to consider the potential for steam and electric power generation when any combustion process is being selected. The potential for in-plant use of steam or electricity usually makes this a viable consideration in light of the high cost for fuel. However, the capital costs are significantly higher and each facility must be studied on its own merits.

Costs vary from 8 to 15 dollars per ton (0.88–1.7¢/kg) where the sludge can be directly incorporated into a combined solid waste incinerator to as much as 20 to 30 dollars per ton (2.2–3.3¢/kg) in sludge-only incinerators. These costs are on an as-received basis and must be corrected for moisture content to determine the cost on a dry solids basis. It is reasonable to expect that the additional cost of steam or electric power generation would essentially be offset by selling the power thus generated or substituting it for otherwise purchased power.

Beneficial Reuse

General Concepts

The foregoing discussion was pointed to wastewater treatment plant sludges considered too hazardous for beneficial reuse and which required direct disposal. However, the majority of the sludge quantity produced in this country is probably suitable for beneficial reuse, if properly handled. The emphasis on resource conservation has added further impetus to the beneficial reuse concept and several systems are presently being used successfully with additional systems either in the experi-

mental or early demonstration stage of development.

Most notable of these systems are direct land application of digested sludge in either liquid or dewatered form, trenching of undigested sludge, and various processing with and without nutrient fortification and composting. Concepts range from large-scale land applications to treatment and packaging in small containers for homeowner use.

While processed sludge is more generally useable in its final form with minimal restrictions, special care is required in selecting the site and determining application rates for large-scale land application of unprocessed wastewater plant sludge. Special evaluation of the potential application site as well as testing of the sludge are required. Acceptable land application rates are dependent on the soil and sludge characteristics; land use constraints; concentrations of nitrogen, phosphorus and salts; and concentrations of trace elements. This particular aspect of the land application of sewage sludge has been the subject of considerable research and many technical papers which have established the cautions and parameters involved with the beneficial utilization of sewage sludge (5).

Basic rules must be established for the use of the land after the application of sludge, and care must be taken to enforce these rules. Consequently, the long-range potential appears to be oriented toward controlled processing.

However, it is reasonable to expect that significant quantities of sludge will continue to be incorporated directly on the land for the foreseeable future.

Direct Application of Digested Sludge

The direct land application of digested sludge can be accomplished by liquid spreading, direct injection, or by spreading and either discing or plowing to provide mixing with the soil. In each of these methods, care must be taken to protect adjacent areas from contamination from both surface water runoff and groundwater movement.

Surface drainage must be directed by ditching to collection ponds where testing for contamination can be accomplished. The ponds should be designed to allow storage prior to overflow so that collected water may be treated, if it becomes contaminated, prior to flowing into adjacent surface water courses.

Where soils have a high porosity and offer the potential for leaching of contaminants into shallow groundwater, the area surrounding the application plot should be provided with strategically located groundwater monitoring wells to allow periodic testing for groundwater contamination. A contin-

agency plan for correction of groundwater contamination should be developed.

The most effective method for the controlled application of liquid sludge is injection into the soil by using subsoilers or plows. Application rates of up to 75 tons/acre (16.8 kg/m²) are mechanically achievable but may be wasteful of nitrogen and phosphorus (5).

Dewatered digested sludge can be applied by direct dumping and spreading on the ground surface and then plowed or disced into the soil. While rates of up to 50 dry tons per acre (11.2 kg/m²) can be mechanically achieved, special tracked equipment is usually required to gain the necessary traction on the sludge. Again, care must be taken to determine the acceptable application rate, in order to minimize potential problems. The sludge must be incorporated into the soil within a short period of time, if odor problems are to be avoided.

The direct use of both liquid and dewatered sewage sludge by injection and surface spreading requires that the application be performed during noncropping periods on productive land or on marginal land. Consequently, land for this purpose may only be available seasonally and the problem requires consideration of alternate procedures.

Trenching of Undigested Sludge

Trenching of sludge offers a beneficial compromise to direct landfilling in that large applications can be made on marginal land which can be removed from cropping for an extended period without loss of farm income. While both digested and undigested sludge can be physically trenched on a site, the elimination of the cost for digestion will help offset the cost of application. Theoretical application rates as high as 544 dry metric tons/acre (134 kg/m²) are mechanically achievable while maximum practical application rates of 454 dry metric tons/acre (112 kg/m²) have been achieved in large-scale field applications.

The basic philosophy behind the trenching concept is that the undigested sludge can be applied and allowed to digest in an environmentally acceptable manner underground. The trenching method was developed as the most practical way to achieve high application rates with standard equipment while providing closed system handling and immediate covering at the site.

Trenches are prepared by using a standard tracked trenching machine with indexing capability to minimize caving of previously excavated trenches. Sludge is discharged from the delivery vehicles directly into the receiving hopper of a

positive displacement pump and transported to a previously excavated trench through flexible pipe. As the trench is filled to within approximately 6 in. from the top, the flexible pipe is continually advanced along the trench until the trench is filled. As the trench is filled with the dewatered sludge, the trenching machine proceeds immediately behind, excavating a new parallel trench. Excavated earth from the new trench is conveyed directly to the filled trench to cover the sludge.

This procedure is performed progressively across the trenching plot until the plot is filled. The resulting mounds of cover are left in place over the trenches until testing shows that the digestion process is complete. Once digestion is complete, mixing can occur by cross ripping the trenches with a bulldozer fitted with a ripper tooth, followed by deep discing until satisfactory mixing occurs.

The entire trenching procedure was developed and tested at the pilot level by the Maryland Environmental Service in Cooperation with Biological Waste Management Laboratory, Agriculture Research Service, United States Department of Agriculture, Beltsville, Maryland. The pilot testing was funded in part by the District of Columbia Department of Environmental Services and the US EPA. Testing was performed from January 1972 to January 1974 and indicated no adverse environmental effects from the procedure (6).

As a result of the basic research, site criteria were developed which allowed full-scale operations to be located in Montgomery and Prince George's Counties, Maryland. The Maryland Department of Health and Mental Hygiene, Solid Waste Division, and the Department of Natural Resources, Water Resources Administration cooperated in establishing not only site criteria but also the site preparation requirements for sludge trenching.

Since the sludge trenching is essentially a landfilling concept with potential long-range benefits, sanitary landfill criteria are used to evaluate potential sites. A thorough subsurface investigation is required, groundwater levels must be established for the period of highest groundwater elevation and the soils and geology evaluated.

It is readily recognized that the trenching of large quantities of undigested sewage sludge has limited application. It is also believed that the procedure is environmentally acceptable for the natural processing of potentially hazardous sewage sludge, with soil benefaction on properly selected sites.

The range of costs for the trenching operation is from 34 to 40 dollars per ton (3.7–4.4¢/kg) as received. Correction is required for moisture content to arrive at the cost on a dry ton basis.

Sewage Sludge Processing

General Concepts

Sludge from wastewater treatment plants has been processed in a variety of systems, all designed to convert it to a readily marketable product safe for consumer use. The processes range from open composting to heat treating and include mechanical composting, flash drying, and fortification with additional nutrients. Several systems have been successfully operated with the end product marketed under a variety of names. At the same time several other systems have been operated for short periods and then abandoned due to the high cost of operation and/or the lack of viable markets for the end product.

Flash Drying

Several flash drying systems are available, and new systems are in the experimental stages. In all instances the systems are energy-intensive and expensive to operate. The end product, unless fortified with additional nutrients, is useable only as a low grade fertilizer or soil conditioner. The ready availability of high yield chemical fertilizers, the high cost of the additional application of the dried sludge, explosion potential and the difficulty of handling the end product have all but ruled out basic heat drying from present consideration.

Continuing experimentation indicates that fortification and granulating processes may have future application. Utilizing the excess heat from the incineration of general solid waste shows promise in reducing the fuel requirements, where this heat is available. Air pollution control requirements with the heat drying systems must have a high degree of efficiency and add even more expense than was previously experienced.

A properly designed and operated heat drying plant, with adequate air pollution control, should offer no more adverse environmental impact than any other similar type of manufacturing or industrial facility. The same considerations are required in heat dryer facility designs as are necessary for sludge incinerators, with the added consideration of packaging and handling the end product.

Costs for heat drying vary considerably as a result of the system used and the controls provided. A range of from 20 to 40 dollars per ton (2.2–4.4¢/kg) as received is not uncommon. Frequently, the revenue from sales is essentially offset by the cost of packaging and/or transporting to the user.

Composting

Composting is the natural way to recycle organic wastes and has been used from the beginning of time. Sewage sludge, other solid wastes and a combination of both have been composted by a variety of processes throughout the world. The highest degree of success has occurred in countries with relatively low standards of living where the luxury of disposal does not exist. With the recent considerations of energy and resource conservation, the process is gaining new popularity in this country. Recently, composting of sludge alone has been considered as a viable alternative for sludge management.

The composting process results in an easy to handle, dry product essentially free from odor which is readily useable as a soil conditioner. As with heat dried sludge, fortification with additional nutrients will enhance its use as a fertilizer. Markets appear to be developing based on recent research in sludge composting and consist of sod farming, corn production, mulch supplementation in nurseries and soil conditioning in the reclamation of strip mines. As with the other land application methods, the characteristics of the composted product and the soil must be evaluated to determine suitable application rates.

Although mechanical composting processes have been developed and tested (7), recent research by the Agriculture Research Service at Beltsville, Maryland, has developed two processes for stabilizing wastewater plant sludges. A windrow process for composting digested sludge was expanded from earlier Los Angeles open windrow composting experience. Subsequently, a forced aeration process has been developed for composting either digested or undigested sludge.

The windrow process is performed in the open on a stabilized pad and consists of multiple operations (5, 8, 9). Woodchips from shredders at clearing and grubbing operations are used as a bulking agent at a ratio of 1:3 by volume. The woodchips and sludge are placed in windrows and mixed daily for approximately 2 weeks with a mechanical compost machine. After spreading and air drying, the compost is stacked in piles in a storage area for further stabilization and pathogen reduction (9). After approximately 30 days in storage, the material is screened to remove the woodchips for reuse as the bulking agent. The screened compost is then ready for use.

While the windrow process is essentially odor free when digested sludge is used, attempts to windrow-compost undigested sludge created a high level of noxious odors; thus the aerated pile process

was developed (10-12). Under this process, perforated metal pipes are laid on the ground and covered by woodchips or previously composted sludge to a depth of 30 cm to absorb liquids and prevent plugging of the perforated pipes. A mixture of sludge and woodchips in the same ratio as the windrow method are placed over the chip-protected pipe to a depth limited by the front end loader used to construct the pile. The entire pile is covered with a 30 cm thickness of compost to insulate the pile and minimize the escape of odors. The vent piping is connected to the suction side of a centrifugal blower with suction applied at various rates to provide proper oxygen concentrations of between 5 and 15%. Air removed from the pile is passed through previously processed compost for odor control.

Suction is applied intermittently on approximately 10-min cycles for a full 21-day compost period. During the off cycle, vacuum is lost, and condensate flows from the pile at a rate reported to be approximately 1 gal/ton (4 ml/kg) per day. As with windrow composting, the compost is moved to a stacked storage pile for curing and further pathogen kill. Screening to separate the woodchips is performed after approximately 30 days curing.

The compost facility consists essentially of an open air stabilized pad provided with drainage diversion of rainwater to a holding pond for treatment by spray irrigation on adjacent woodland and fields. Future facilities can minimize the runoff by providing an open-sided, roofed structure to divert a major portion of rainfall from contact with the composting material thus reducing the contaminated water treatment quantity and cost.

While the composting process, with rainfall and odor control, is essentially environmentally acceptable with little or no actual impact, it is considered desirable to provide a vegetated buffer area around the site to minimize its visibility from surrounding areas. The operation is agricultural in nature and is compatible with other agricultural activity. However, the suggested screening is a desirable adjunct when the potential for visibility impact to the surrounding area is considered.

As with all other sludge management processes, the cost for composting will vary with the degree of site preparation and type of sludge processed. The compost costs experienced at the Beltsville project are computed to range from approximately 10 to 15 dollars per ton (1.1-1.7¢/kg) on an as-received basis from a reported cost range of 35 to 50 dollars per dry ton (3.8-5.5¢/kg) (10).

Conclusions

Wastewater treatment plant sludges vary in their degree of hazard depending on their characteristics. Where the sludges are too hazardous for beneficial land application, they must be considered suitable only for disposal. The primary methods available under present technology are landfilling in a designated hazardous waste sanitary landfill and incineration with adequate air pollution controls.

Where sludges offer the potential for beneficial reuse, several methods of direct land application are in use, all of which require continual policing to enforce the necessary rules for application.

An alternative to direct application is pre-treating or processing to create a stable, environmentally safe product suitable for more varied application. Of the processing concepts available, the aerated pile composting procedure developed by the Agriculture Research Service at Beltsville, Maryland, appears to offer the least costly, most environmentally sound system for consideration.

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